ROUTING AND ACTION

MEMORANDUM

ROUTING

TO:(1) Electronics Division (Clark, William)

Report is available for review

(2) Proposal Files Report No.: -DRP Proposal Number: 58269-EL-DRP.10

DESCRIPTION OF MATERIAL

CONTRACT OR GRANT NUMBER: W911NF-10-1-0214

INSTITUTION: Columbia University

PRINCIPAL INVESTIGATOR: Shree Nayar

TYPE REPORT: Final Report

DATE RECEIVED: 2/11/14 4:27PM

PERIOD COVERED: 7/1/10 12:00AM through 6/30/12 12:00AM

TITLE: Final Report: Imaging System Using Shared Optics and Aberration Exploitation

ACTION TAKEN BY DIVISION

(x) Report has been reviewed for technical sufficiency and IS [x] IS NOT [ ] satisfactory.

(x) Material has been given an OPSEC review and it has been determined to be non sensitive and, except for manuscripts and progress reports, suitable for public release.

(x) Perfomance of the research effort was accomplished in a satisfactory manner and all other technical requirements have been fulfilled.

(x) Based upon my knowledge of the research project, I agree with the patent information disclosed.

Approved by SSL\WILLIAM.CLARK on 2/20/14 10:50AM

ARO FORM 36-E

REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
11-02-2014	Final Report	1-Jul-2010 - 30-Jun-2012

4. TITLE AND SUBTITLE
Final Report: Imaging System Using Shared Optics and Aberration Exploitation

5a. CONTRACT NUMBER
W911NF-10-1-0214

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
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6. AUTHORS
C. Zhou, O. Cossairt, D. Miau, S.K. Nayar

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
Columbia University
615 West 131st Street
Room 254, MC 8725
New York, NY 10027 -7922

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
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11. SPONSOR/MONITOR'S REPORT NUMBER(S)
58269-EL-DRP.10

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
The resolution of a camera system determines the fidelity of visual features in an image. Higher resolution implies greater fidelity, and thus greater accuracy when performing automated vision tasks such as object detection, recognition, and tracking. However the resolution of any camera is fundamentally limited by geometric aberrations. In the past it has generally been accepted that the resolution of lenses with geometric aberrations cannot be increased beyond a certain threshold. In this work we aim to overcome this limitation and demonstrate very high resolution imagery for aberrated lenses through the use of hybrid optical and image processing design.

15. SUBJECT TERMS
Gigapixel Computational Imaging, Computational Cameras, Spherical Optics

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Shree Nayar
UU	UU	UU	UU		19b. TELEPHONE NUMBER 212-939-7092

Report Title

Final Report: Imaging System Using Shared Optics and Aberration Exploitation

ABSTRACT

The resolution of a camera system determines the fidelity of visual features in an image. Higher resolution implies greater fidelity, and thus greater accuracy when performing automated vision tasks such as object detection, recognition, and tracking. However the resolution of any camera is fundamentally limited by geometric aberrations. In the past it has generally been accepted that the resolution of lenses with geometric aberrations cannot be increased beyond a certain threshold. In this work we aim to overcome this limitation and demonstrate very high resolution imagery for aberrated lenses through the use of hybrid optical and image processing design.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
05/15/2012	6.00	Oliver S. Cossairt, Daniel Miau, Shree K. Nayar. Scaling law for computational imaging using spherical optics, Journal of the Optical Society of America A, (11 2011): 0. doi: 10.1364/JOSAA.28.002540
05/15/2012	2.00	Changyin Zhou, S. K. Nayar. Computational Cameras: Convergence of Optics and Processing, IEEE Transactions on Image Processing, (12 2011): 0. doi: 10.1109/TIP.2011.2171700
TOTAL:	**2**	

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received		Paper
TOTAL:		

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper	
05/15/2012	4.00	Oliver S. Cossairt, Daniel Miau, Shree K. Nayar. Gigapixel Computational Imaging, 2011 IEEE International Conference on Computational Photography (ICCP). 08-APR-11, Pittsburgh, PA, USA. : ,

TOTAL: **1**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received	Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Shree Nayar, Elected to American Academy of Arts and Sciences, 2011.

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Oliver Cossairt	1.00	
Daniel Miau	1.00	
Changyin Zhou	1.00	
FTE Equivalent:	**3.00**	
Total Number:	**3**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Oliver Cossairt	1.00
FTE Equivalent:	**1.00**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Shree K. Nayar	0.00	Yes
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:..... 0.00

Names of Personnel receiving masters degrees

NAME
Daniel Miau
Total Number: 1

Names of personnel receiving PHDs

NAME
Oliver S. Cossairt
Total Number: 1

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

We have derived an analytic scaling law that shows that, for lenses with spherical aberrations, resolution can be increased beyond the aberration limit by applying a post-capture deblurring step. We have also shown that resolution can be further increased when image priors are introduced

In Year I, we developed our scaling law based on empirical evidence about the PSF properties of ball lenses. We used our scaling law to design and build a spherical lens imaging system with very high resolution (gigapixel). We demonstrated proof-of-concept operation by sequentially scanning a sensor to multiple locations behind the ball lens, producing several high quality gigapixel images. In Year II we further analyzed the properties of ball lenses, deriving analytic expressions for the PSF and MTF of ball lens systems, deriving a rigorous theoretical basis for our empirical observations in Year I. In addition, we studied the tradeoff between lens complexity and deblurring performance for monocentric ball lens systems. Our observations indicate that there is a law of diminishing returns when increasing the complexity of ball lenses by introducing the number of discrete optical elements (i.e. spherical shells manufactured from different materials). Future work will investigate if similar principles apply of general, non-monocentric imaging systems as well.

Technology Transfer